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Impact of Alkalinity Sources on the Life Cycle Energy Efficiency of CO_2 Mineralization Technologies

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Project Description

A holistic, transparent life cycle assessment model of a variety of aqueous mineral carbonation processes was built using a hybrid process model and economic input-output life cycle assessment approach (hybrid EIO-LCA). In this study we seek to evaluate the tradeoffs in using various reaction enhancement process schemes while considering the larger life cycle impacts on energy use and material consumption. While previous studies have identified process conditions optimal for enhancing the chemical rates of reactions, no study has yet performed a scheme that optimizes these conditions with respect to engineering and economic consideration for the goal of producing a viable carbonation process. Results of this work will help to determine the mitigation potential of CO_2 mineralization.
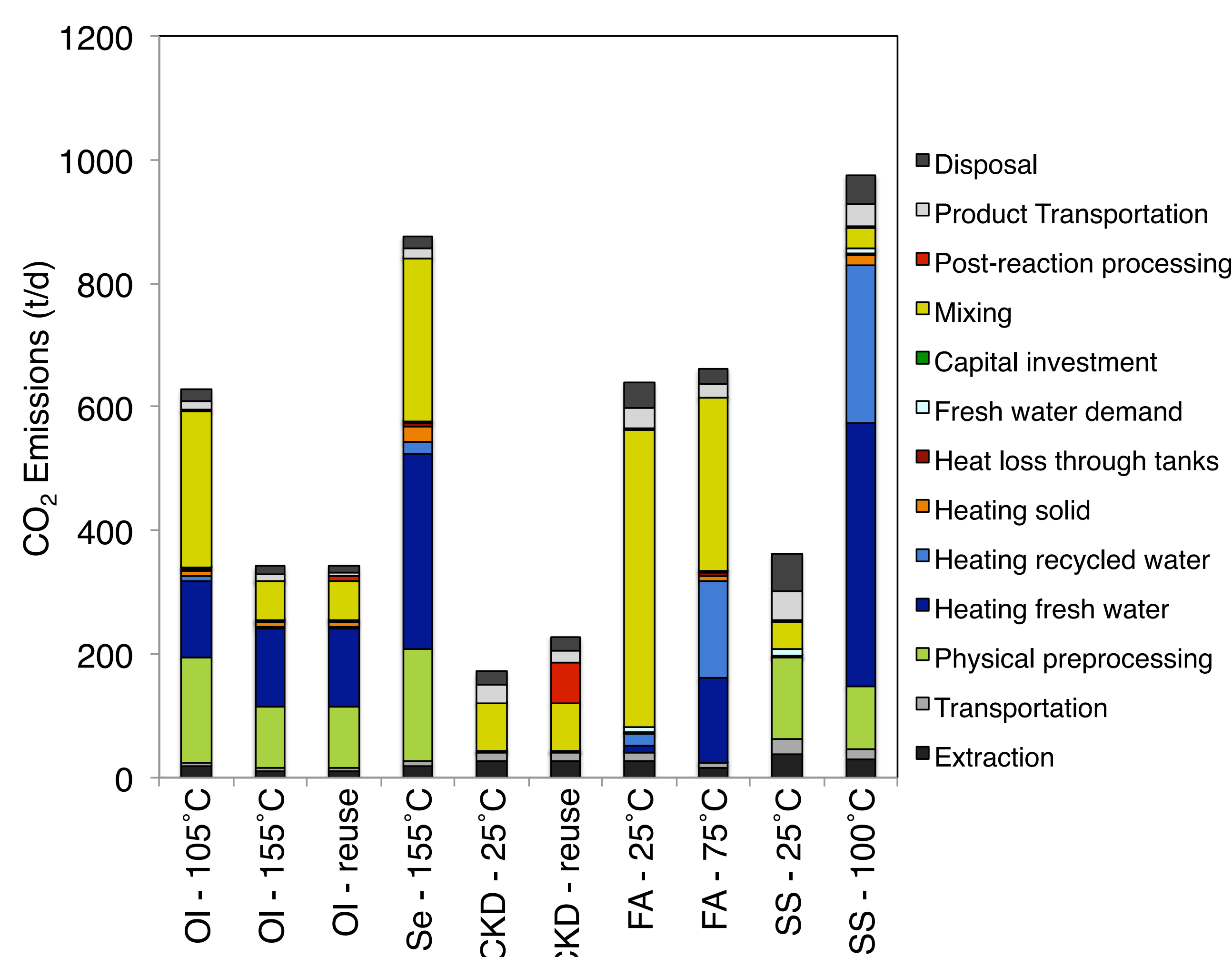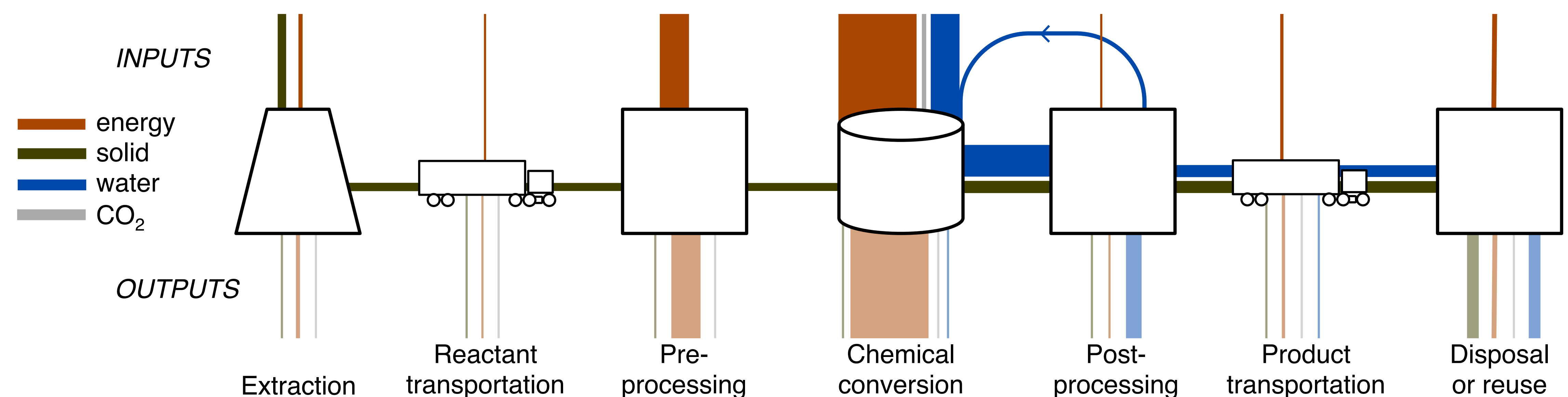
Accomplishments and Current Status

The LCA model allows for the evaluation of the tradeoffs between different reaction enhancement processes while considering the larger lifecycle impacts on energy use and material consumption. The net CO_2 storage potential of aqueous mineral carbonation has been evaluated for serpentine (Se), olivine (Ol), cement kiln dust (CKD), fly ash (FA), and steel slag (SS) across a range of reaction conditions and process parameters.

• 8 generic process stages comprise the process-model core of the LCA tool (**Figure 1**).
• The contribution to CO_2 emissions for select mineral carbonation processes reveals that mixing, heating, and grinding are the main energy drivers (**Figure 2**).

Additionally, the geographic relationship between carbonation resources (i.e., industrial alkaline sources) and products (i.e., synthetic aggregate), CO_2 point-sources, and aggregate markets has been investigated (**Figures 3, 4**).

Figure 1. Life cycle process model schematic for aqueous mineral carbonation of 1,000 t CO_2, based on the Olivine – 155 °C case; line thickness is scaled to the energy and mass fluxes.

Figure 2. CO_2 emissions per 1,000 t-CO_2/d sequestered for the carbonation processes with net CO_2 mitigation potential.

Outcomes and Applications

The life cycle assessment of aqueous mineral carbonation suggests that a variety of alkalinity sources and process configurations are capable of net CO_2 reductions.

The results of this work provide guidance for the development and optimization of viable mineral carbonation technologies. For example:

• Process efficiency is maximized by increasing extent reacted through the most energetically favorable enhancement measure
• Mixing, heating, and grinding are the main energy drivers across all processes
• Reuse of carbonate as aggregate does not necessarily improve life cycle energy efficiency
• Not all alkalinity sources benefit from high reaction temperatures
• Any steps to increase reaction rates would dramatically improve process efficiency.

The total CO_2 storage potential for the alkalinity sources considered in the United States ranges from 1.3% to 23.7% of U.S. CO_2 emissions, depending on the assumed availability of natural alkalinity sources and efficiency of the mineral carbonation processes.
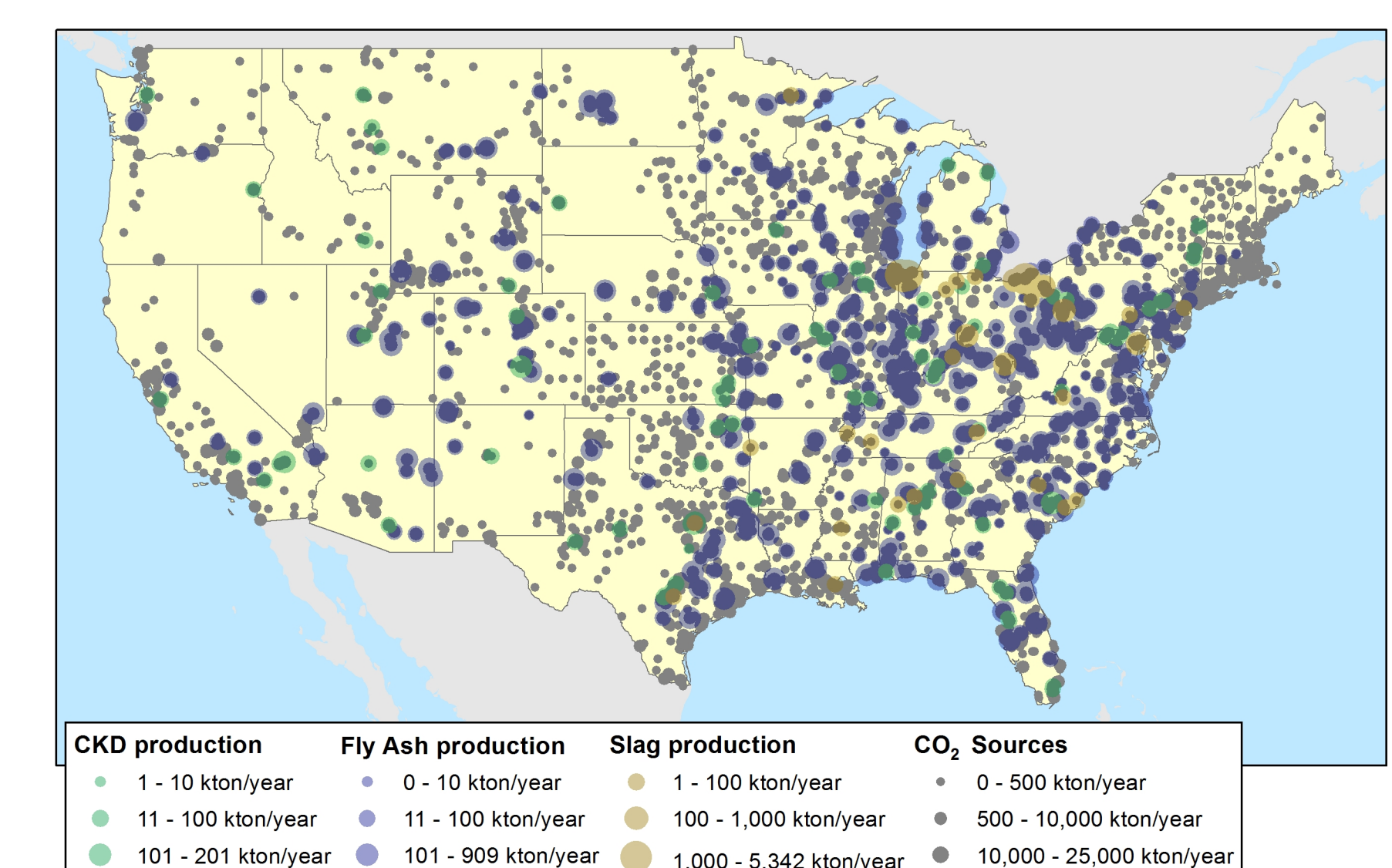
Figure 3. Industrial alkaline sources and CO_2 point-sources in the conterminous United States.
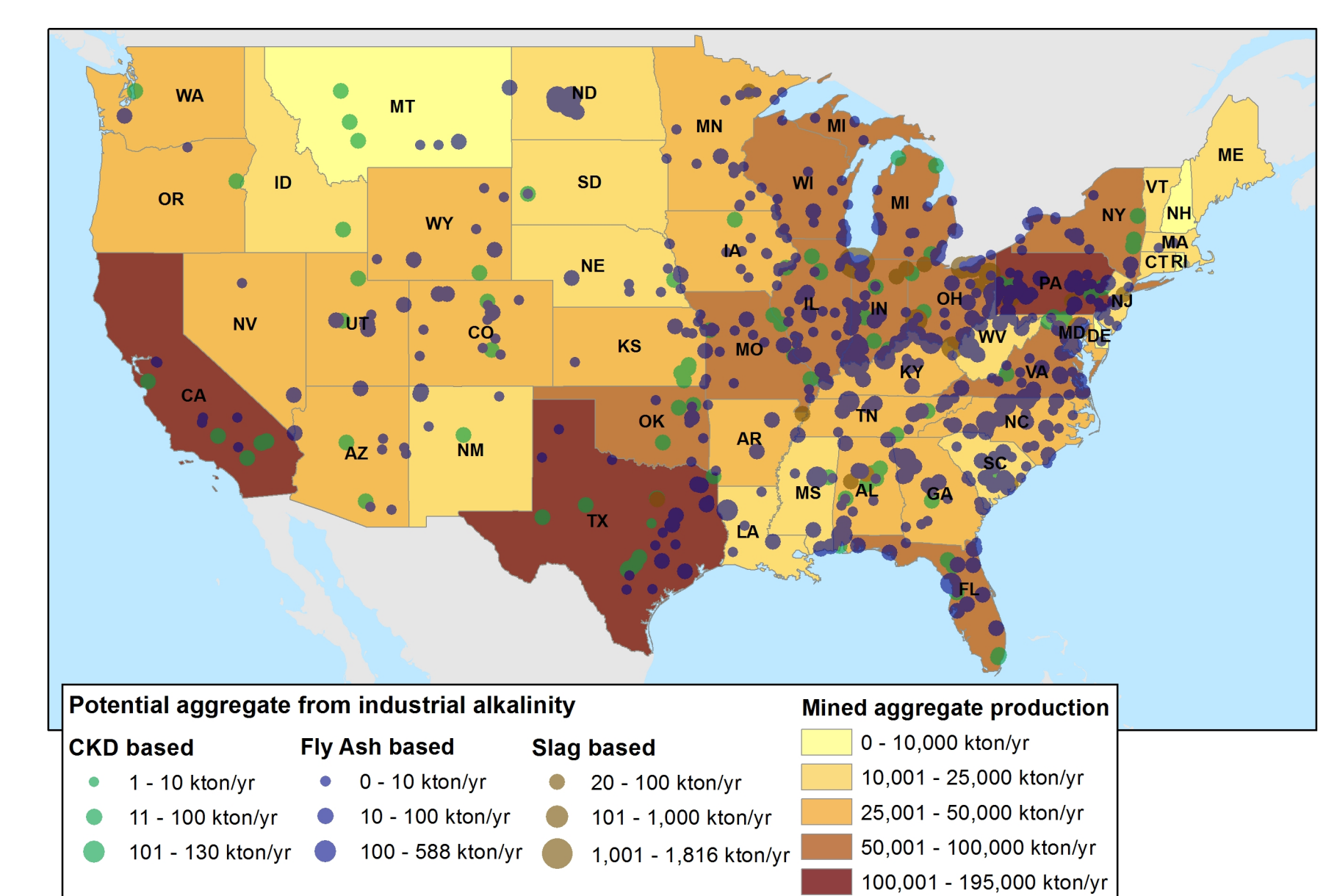
Figure 4. Comparison of absolute mined to potential synthetic production of aggregate.